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THE MACHO PROJECT LARGE MAGELLANIC CLOUD VARIABLE STAR INVENTORY. IV. NEW R CORONAE BOREALIS STARS

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ABSTRACT

We report the discovery of two new R Coronae Borealis (RCB) stars in the LMC using the MACHO project photometry database. The identification of both stars has been confirmed spectroscopically. One is a cool RCB star ($T_{\rm eff} \sim 5000$ K), characterized by very strong Swan bands of C_2 and violet bands of CN, and weak or absent Balmer lines, G band, and $^{12}C^{13}C$ bands. The second star is an example of a hot RCB star, of which only three were previously known to exist in the Galaxy and none in the LMC. Its spectrum is characterized by several C II lines in emission. Both stars have shown deep declines of $\Delta V \geq 4$ mag in brightness. The new stars are significantly fainter at maximum light than the three previously known LMC RCB stars. The amount of reddening toward these stars is somewhat uncertain, but both seem to have absolute magnitudes, M_V, $\sim$0.5 mag fainter than the other three stars. Estimates of $M_{\rm bol}$ find that the hot RCB star lies in the range of the other three stars, while the cool RCB star is fainter. The two cool LMC RCB stars are the faintest at $M_{\rm bol}$. The discovery of these two new stars brings to five the number of known RCB stars in the LMC, and it demonstrates the utility of the MACHO photometric database for the discovery of new RCB stars.

Subject headings: gravitational lensing — stars: variables: other (R Coronae Borealis) — Magellanic Clouds

1. INTRODUCTION

The R Coronae Borealis (hereafter RCB) stars represent a rare type of hydrogen-deficient carbon-rich supergiants, which undergo very spectacular declines in visual brightness of up to 8 mag at apparently irregular intervals (Clayton 1996). A cloud of carbon-rich dust forms along the line of sight to the RCB star eclipsing the photosphere, causing a severe drop in its brightness and the appearance of a rich emission-line spectrum. As the dust cloud disperses, the star returns to maximum light. RCB stars have a wide range of temperatures, but they can be divided simply into three groups, cool ($\sim$5000 K), warm ($\sim$7000 K), and hot ($\sim$20,000 K). Typical representatives of these groups are S Apodis, R Coronae Borealis, and V348 Sagittarii, respectively. Most RCB stars fall in the warm category. Hot RCB stars are quite rare, with only three examples known. The typical warm RCB spectrum at maximum light looks like an F or G supergiant but with a few important differences: the Balmer lines are very weak or absent, and the spectrum contains many lines of neutral carbon, as well as bands of C_2 and CN. The cool RCB-type spectrum resembles the warm type but with much stronger molecular absorption bands. The hot RCB stars show similar light-curve behavior to the cooler stars, but their spectra are very different (Pollacco & Hill 1991). The spectrum of V348 Sgr, the best studied hot-type star, shows strong emission lines of C II and He I as well as the Balmer lines, Ne I, and various forbidden lines (Dahari & Osterbrock 1984). Most RCB stars in all three categories show excesses at near-IR and *IRAS* wavelengths.

The RCB stars are very rare, either because they form only in unusual circumstances or because they are a brief episode in stellar evolution. Only about 30 RCB stars are known in the Galaxy, and until now only three in the LMC, despite their high-intrinsic luminosities. Their evolutionary history remains very uncertain. Two major evolutionary models have been suggested for the origin of RCB stars, the double degenerate and the final helium shell flash conjectures (Schönberner 1986; Renzini 1990; Iben, Tutukov, & Yungelson 1996). Both involve expanding white dwarfs to the supergiant sizes assumed for RCB stars. A third model suggests that RCB stars are binaries in the second common envelope phase, with a low-mass companion orbiting inside the envelope (Whitney, Soker, & Clayton 1991). Recently,

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Iben et al. (1996) added the merger of a neutron star and a helium-rich star to the list of possible RCB star precursors.

An important input parameter to these models is stellar luminosity. This parameter can only be estimated when the distance to a star is known. However, there is no reliable distance estimate to any Galactic RCB star. Since they are not "normal" stars, their distances can only be estimated if they are associated with an object at a known distance or through other indirect methods. Previous estimates of Galactic RCB star luminosities are summarized in Table 1. In addition, a star in the cluster NGC 6231 was initially identified as an RCB star but turned out to be a normal reddened star (Bessel et al. 1970; Herbig 1972). In a similar manner to Doroshenko et al. (1978), Rosenbush (1981, 1982, 1989, 1995), using estimates of reddening along sight lines to RCB stars and the structure of the interstellar medium, finds a wide range of absolute magnitudes, $M_V = -5$ to $+2.5$. The RCB star V482 Cygni was identified with a quadruple star system containing a K5 III star, based on proximity on the sky implying $M_V = -2.8$ (Gaustad et al. 1988). This association was refuted by Rao & Lambert (1993), who find that V482 Cyg has significantly different radial velocities and interstellar columns than the K5 III star. They estimate a larger distance consistent with an M_V of about -4.6. Other RCB stars, including RY Sagittarii, have close companions, although none have been shown to be physical pairs (Andrews et al. 1967; Feast 1969; Milone 1995). Estimates of Galactic RCB star luminosities differ by factors of up to 10^3.

Because of the absence of reliable distance estimates for the Galactic stars, the LMC RCB stars play a pivotal role in RCB star research. Absolute luminosities can be derived from the LMC RCB stars that are at a known distance. Using their apparent magnitudes and the known distance of the LMC ($m - M = 18.6$), an absolute magnitude M_V of about -4 to -5 is derived. However, this is based on only three stars (Feast 1972). This result, that RCB stars have supergiant size and luminosity, puts strong constraints on the evolutionary models outlined above.

One of the dividends from the search for Massive Compact Halo Objects (MACHOs) toward the LMC is the discovery of a large number of new variable stars. Over 40,000 variables have been discovered thus far (Cook et al. 1995). RCB candidates have been selected on the basis of their light-curve behavior, and they have been confirmed spectroscopically. When only fragmentary light-curve data are available, RCB stars may be confused with symbiotic, cataclysmic, or semiregular variables (Lawson & Cottrell 1990).

2. KNOWN LMC RCB STARS

Outside the Galaxy, only the following three RCB stars have been discovered to date: W Mensae, HV 5637, and HV 12842 (Rodgers 1970; Payne-Gaposchkin 1971; Feast 1972). They are thought to be members of the LMC. Radial velocities for HV 12842 and W Men are appropriate for LMC membership (Feast 1972; Pollard, Cottrell, & Lawson 1994). The radial velocity of HV 5637 is not known. HV 12671 was previously identified as an RCB star but is now thought to be a carbon-symbiotic star (Allen 1980; Lawson et al. 1990). The three LMC RCB stars are listed in Table 2. Photometric coverage has been spotty, but declines have been observed for each of the stars. HV 5637 only has one decline on record and no IR excess (Glass, Lawson, & Laney 1994). It may be similar to the Galactic RCB star, XX Camelopardalis (Clayton 1996). The light-curve behavior of the three stars is summarized in Lawson et al. (1990). Long-term B and V photometry was obtained by Lawson et al. for W Men and HV 12842. A few observations of HV 5637 were also obtained. The V magnitudes at maximum light ($V_{\max}$) are listed in Table 2. The light curves of W Men and HV 12842 demonstrate small-amplitude variations similar to those typically seen in the Galactic stars. Spectra of all three stars were obtained by Feast (1972). The spectra of W Men and HV 12842 show that they belong in the warm RCB group, very similar to R CrB and RY Sgr, showing weak C_2 bands (Rodgers 1970; Feast 1972). HV 5637 is a cool RCB star with a spectrum similar to S Aps, having very strong bands of C_2. The $B-V$ of HV 5637 implies a spectral type of K2 (Glass et al. 1994). For W Men and HV 12842, the $B-V$ colors indicate mid-F.

Eggen (1970) points out that the $U - B$ colors are quite a bit bluer for W Men (an LMC RCB star) than for RY Sgr or R CrB (Galactic RCB stars). Pollard et al. (1994) have measured fine abundances for HV 12842 and W Men. They are similar in composition to the majority of Galactic RCB

TABLE 1

LUMINOSITY ESTIMATES FOR GALACTIC RCB STARS

Name	M_V	Method	References
R CrB	−3.1	Member Wolf 630 group	Eggen 1969
R CrB	−4.6	Mg II emission core	Rao, Nandy, & Bappu 1981
RY Sgr	−4	Close companion	Andrews et al. 1967
SU Tau	−3	I.S. polarization	Doroshenko et al. 1978
V482 Cyg......	−2.8	Close companion	Gaustad et al. 1988
V482 Cyg......	−4.6	Radial velocity	Rao & Lambert 1993
V348 Sgr	−4.8	Radial velocity	Schönberner 1986

TABLE 2

LMC RCB STARS

Name	$V_{\max}$	$B-V$	$(V-R)_{KC}$	$E(B-V)$	V_0	M_V	M_{Bol}	T_{eff}
HV 5637	14.8	1.25	...	0.1	14.5	−4.1	−4.6	5000
W Men.................................	13.8	0.37	0.23	0.1	13.5	−5.1	−5.3	7000
HV 12842.............................	13.7	0.50	...	0.2	13.1	−5.5	−5.7	7000
MACHO*05:33:49.1–70:13:22......	16.1	...	0.1	0.3	15.2	−3.4	−5.4	20000
MACHO*05:32:13.3–69:55:59......	16.3	...	0.8	0.4	15.1	−3.5	−4.0	5000

stars except that they are iron deficient (Lambert & Rao 1994). This is perhaps not surprising, since, in general, stars in the LMC are iron deficient. The RCB stars are characterized by extreme hydrogen deficiency and an overabundance of carbon. In general, $[C/H] \geq 10^3$, $[C/Fe] \sim 1$, $[X/Fe] \sim$ solar for most other species up to iron peak elements, and $^{12}C/^{13}C \geq 100$ (Pollard et al. 1994). The high $^{12}C/^{13}C$ ratio implies the presence of material processed by helium burning. Lambert & Rao (1994), with their larger sample, find that 14 of 18 RCB stars have quite similar compositions. In this group, only hydrogen and lithium abundances vary strongly from star to star. Nitrogen and sodium are also overabundant. Among the four RCB stars that have unusual compositions—V854 Centauri, V Coronae Australis, VZ Sagittarii, and V3795 Sagittarii—two are relatively hydrogen rich and all are iron poor, as are the LMC RCB stars (Lambert & Rao 1994). Glass et al. (1994) find long-term variations in the near-IR brightness in two of the LMC RCB stars, and they found a possible correlation between the IR brightness and decline activity for W Men. This behavior is similar to that seen in Galactic RCB stars. Most also show an excess at *IRAS* wavelengths. One LMC RCB star, HV 12842, seems to have been detected in the *IRAS* Faint Source Survey (Moshir et al. 1992) at a level of about 0.09 Jy at 12 μm. Despite some small differences in abundances and colors, the LMC RCB stars seem to be quite similar to their Galactic counterparts.

3. NEW LMC RCB STARS

3.1. *MACHO Photometry*

The MACHO project (Alcock et al. 1992) is an astronomical survey experiment designed to obtain multiepoch, two-color CCD photometry of millions of stars in the LMC (also, the Galactic bulge and SMC). The survey makes use of a dedicated 1.27 m telescope at Mount Stromlo, Australia, and because of its southern latitude, it is able to obtain observations of the LMC year round (Hart et al. 1996). The camera built specifically for this project (Stubbs et al. 1993) has a field of view of 0.5 deg^2, which is achieved by imaging at prime focus. Observations are obtained in two bandpasses simultaneously, using a dichroic beam splitter to direct the "blue" (~4400–5900 Å) and "red" (~5900–7800 Å) light onto 2 × 2 mosaics of 2048 × 2048 Loral CCDs. Hereafter, these bandpasses will be referred to as $V_{\rm MACHO}$ and $R_{\rm MACHO}$, respectively. Images are obtained and read out simultaneously. The 15 μm pixel size maps to 0.″63 on the sky. The data were reduced using a profile-fitting photometry routine known as SODOPHOT, which is derived from DoPHOT (Mateo & Schechter 1989). This implementation employs a single starlist that is generated from frames obtained in good seeing. The results reported in this survey comprise only a fraction of the planned data acquisition of the MACHO project. At present, most of the LMC data from the first 3 years has been processed, consisting of some 5500 frames distributed over 22 fields; this sample contains a total of approximately 8 million stars. These data have been searched for variable stars and microlensing candidates, and over 40,000 variables have been found, most of which are newly discovered. The great majority of these fall into four well-known classes: there are approximately 25,000 very red semiregular or irregular variables, 1500 Cepheids, 8000 RR Lyraes, and 1200 eclipsing binaries (Cook et al. 1995). Typically, the data set for a given star covers a time span of about 1200 days and contains ~700 photometric measurements (multiple observations are obtained on a given night whenever conditions allow). The output photometry contains flags indicating suspicion of errors caused by crowding, seeing, array defects, and radiation events.

The database of MACHO variables was searched for stars that underwent large sudden brightness variations. The light curves of these large-amplitude variables were then viewed by eye. Candidates were selected as having distinctive RCB light-curve behavior. RCB stars are true irregular variables (Clayton, Whitney, & Mattei 1993). A star may have several declines in 1 yr or go 10 yr or more without any declines. So any search over a short time period will detect only a fraction of the RCB stars. One year of MACHO photometry has been searched so far. Two candidates, MACHO*05:33:49.1–70:13:22 and MACHO*05:32:13.3–69:55:59, that show light curves characteristic of RCB stars have been found. These coordinates are J2000. Finding charts for the two stars are shown in Figures 1 and 2. The fields are 161 arcsec^2; north is up, and east is to the left. The light curves are shown in Figures 3 and 4. These figures include all available MACHO data up to the present. Only data free from suspected errors are plotted, resulting in output photometry lists of length 394 (MACHO*05:33:49.1–70:13:22) and 462 (MACHO*05:32:13.3–69:55:59). Typical photometric uncertainties are in the range 1.5%–2%. The $V_{\rm MACHO}$ and $R_{\rm MACHO}$ bandpasses have been converted to Kron-Cousins (KC) V and R bandpasses using the latest transformations, which are determined from the ongoing internal calibrations of the MACHO database. The $(V-R)_{\rm KC}$ colors are also plotted in Figures 3 and 4. The color-magnitude diagrams for the fields of the two stars are shown in Figures 5 and 6. Both stars lie among the post-AGB stars.

3.2. *Spectroscopic Data*

Spectroscopic observations were obtained of MACHO*05:33:49.1–70:13:22 and MACHO*05:32:13.3–69:55:59 in 1995 November, when both stars were at light maximum. The spectra were obtained with the Reticon photon-counting system on the image-tube spectrograph on the SAAO 1.9 m telescope at Sutherland, South Africa. The grating used gives a reciprocal dispersion of 100 Å mm^{-1} and a resolution of approximately 4 Å, giving a useful range of about 3600–5200 Å at the angle setting used. The spectrograph is a two-aperture instrument recording the star and sky simultaneously. Normal operating procedure is to measure the star through one aperture and then the other, in such a way that the sequence goes arc, star in A, arc, star in B, arc. Each star is then wavelength calibrated by the two arcs on either side, and the results of star in A and B are added together after flat-field correction and sky subtraction. Flux calibration is done by observing one standard star each night. In the case of MACHO*05:33:49.1–70:13:22, all the spectra were added together and a flux standard from one night was used. The flux calibration is not accurate because the instrument is not a spectrophotometer and observations are sometimes made in nonphotometric conditions; hence, light losses vary with time and seeing. Although the absolute calibration is uncertain, the relative fluxes should be reliable. MACHO*05:32:13.3–69:55:59 was observed on one night (2 × 1500 s) and MACHO*05:33:49.1–70:13:22 on three nights

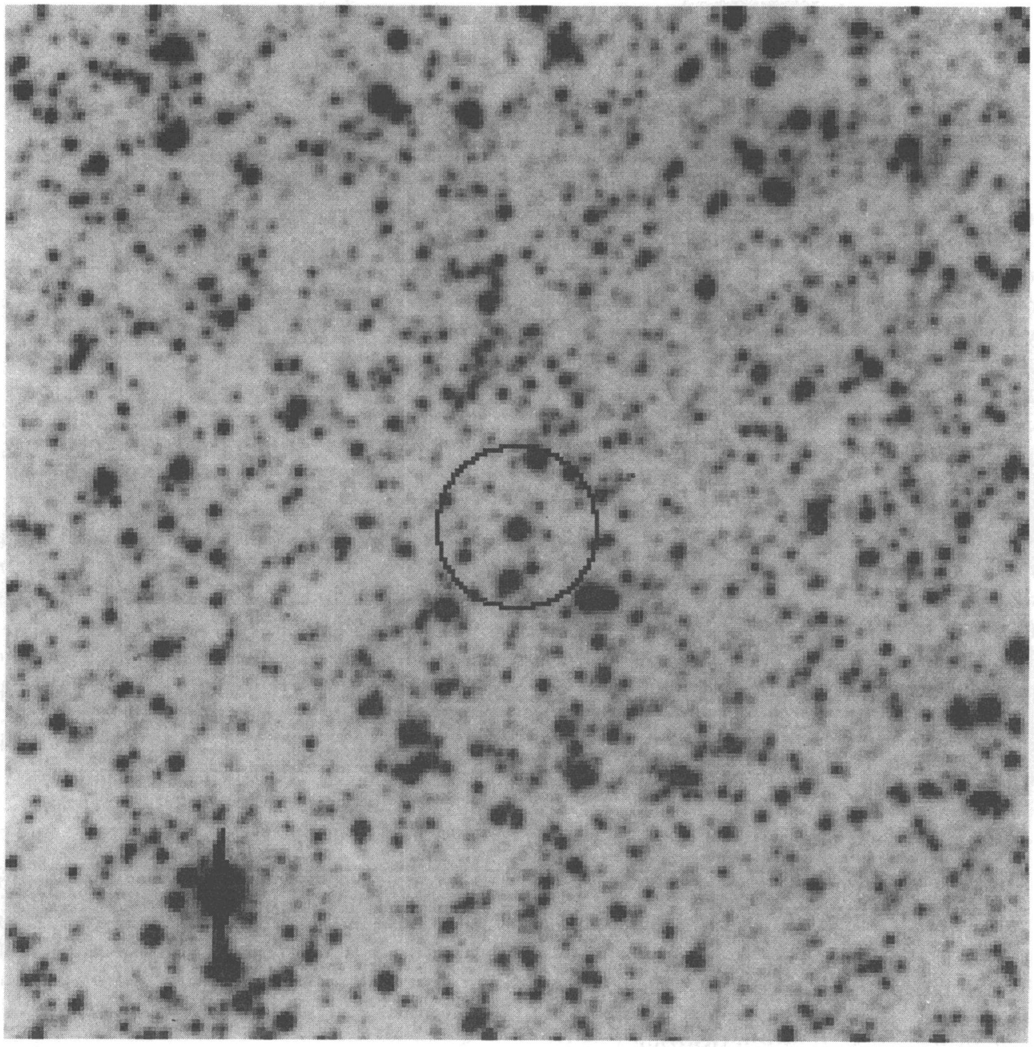

FIG. 1.—Finding chart for MACHO*05:33:49.1–70:13:22. Field is 161 arcsec^2. North is up, and east is to the left.

(2×1000 s, 2×1200 s, and 2×1000 s). The spectra are shown in Figures 7 and 8. These spectra are sums of all individual scans.

4. DISCUSSION

Figure 3 shows the light curve of MACHO*05:33:49.1–70:13:22. Almost the entire 1200 days of coverage involves one deep decline of $\Delta V \geq 4$ mag. The decline begins around JD 2,448,925, with a steep drop of $\sim$4 mag in a few days. There is a slight recovery around JD 2,449,000, followed by another fading and then a slow recovery to maximum light. This light curve is typical of an RCB star decline. The final recovery to maximum light can be gradual as the dust cloud disperses, sometimes taking several years (e.g., Alexander et al. 1972). Figure 4 shows the light curve of MACHO*05:32:13.3–69:55:59. It is quite active, showing three major declines around JD 2,448,900, JD 2,449,325, and JD 2,449,650. There is a great variation in decline activity from star to star and also from time to time for an individual star (Clayton 1996). The Galactic RCB star, V854 Cen, has shown similar activity to MACHO*05:32:13.3–69:55:59 in the last few years (Lawson et al. 1992). Both MACHO*05:33:49.1–70:13:22 and MACHO*05:32:13.3–69:55:59 show small-amplitude variations at maximum light similar to other RCB stars.

Figures 3 and 4 also show the $(V-R)_{KC}$ color behavior. MACHO*05:33:49.1–70:13:22 becomes redder at the beginning of the decline and returns to its normal color as it returns to maximum light. Early and late in a decline, the star is reddened by a dust cloud that is not optically thick. Deep in a decline, the cloud may be optically thick in such a way that reddening may not be seen. MACHO*05:32:13.3–69:55:59 shows $(V-R)_{KC}$ colors, which become bluer at the onset of the decline and then return to normal as the star recovers to maximum. RCB stars experience red and blue declines (Cottrell, Lawson, & Buchhorn 1990). The colors can vary from decline to decline, depending on how much of the photosphere and the emission-line regions are obscured by dust, by the optical depth of the dust, and by the relative strength of the emission lines. Sometimes very early in a decline, at first the colors are unchanged, and then they become bluer. This can occur if the forming cloud is smaller than the photosphere and some unreddened starlight is still visible (Cottrell et al. 1990). Red declines occur if the forming cloud covers the entire photosphere. It is notable that MACHO*05:32:13.3–69:55:59 has had three blue declines in a row. Unfortunately, the data for Galactic RCB stars are sparse, and so the relative frequency of red and blue declines is not known. For the LMC RCB stars, another possibility is confusion with a blue star in the aperture, although no such star is visible on the CCD frames.

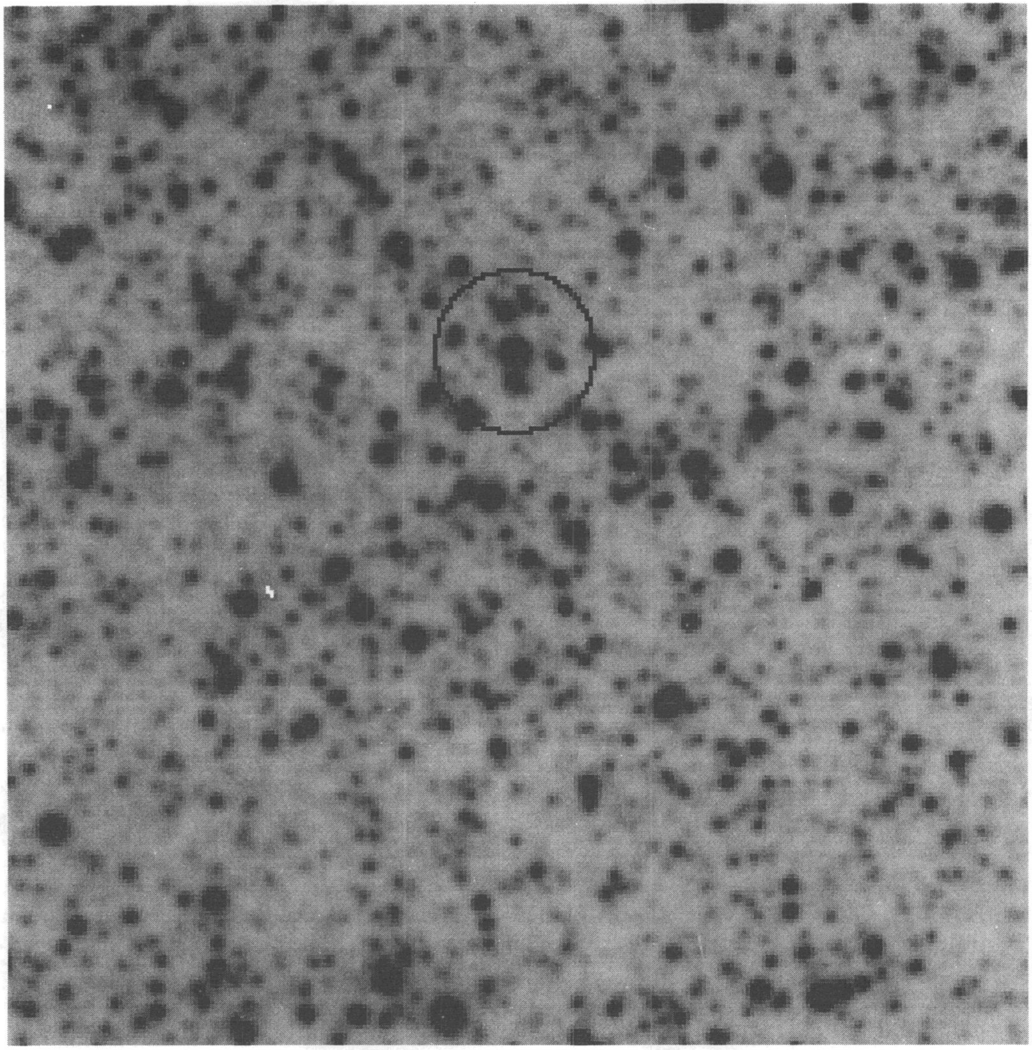

FIG. 2.—Finding chart for MACHO*05:32:13.3−69:55:59. Field is 161 arcsec^2. North is up, and east is to the left.

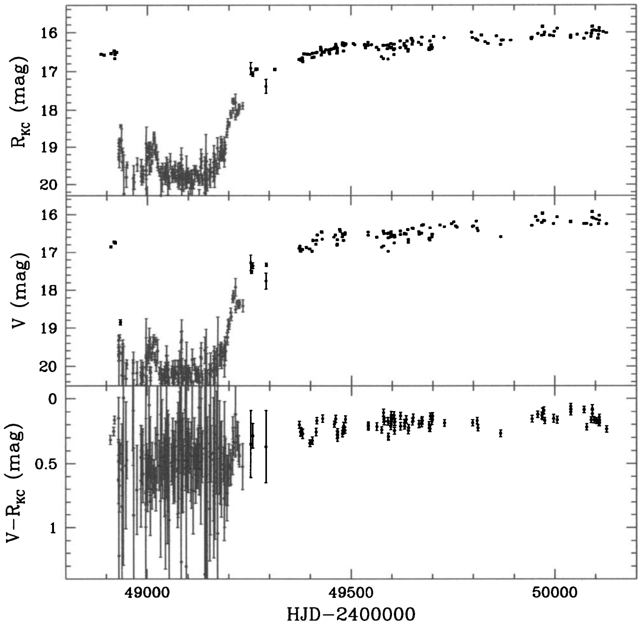

FIG. 3.—MACHO photometry for MACHO*05:33:49.1−70:13:22. Data have been converted to Kron-Cousins V- and R-bands. See text.

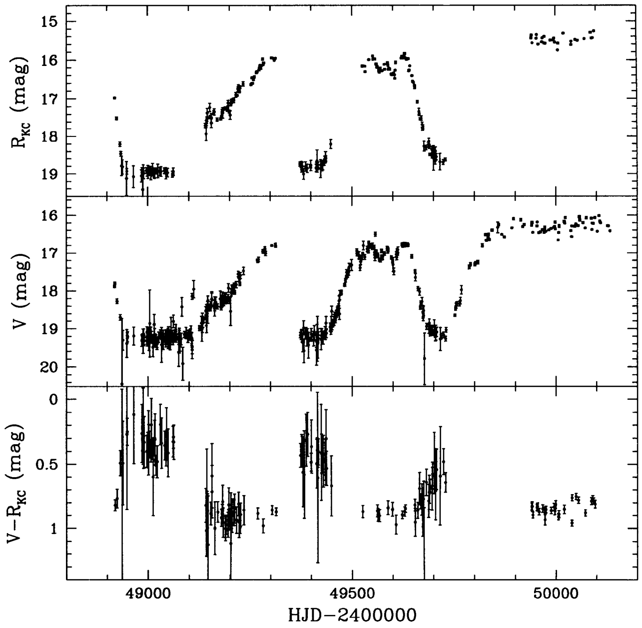

FIG. 4.—MACHO photometry for MACHO*05:32:13.3−69:55:59. Data have been converted to Kron-Cousins V- and R-bands. See text.

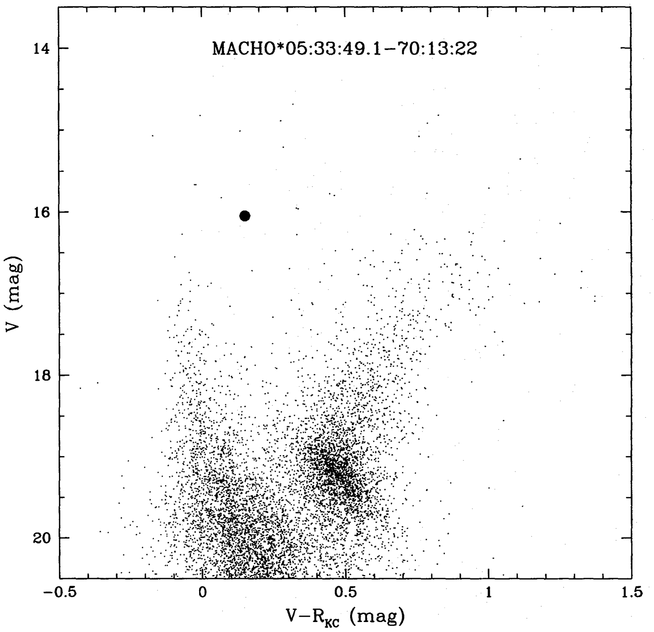

FIG. 5.—Color-magnitude diagram for stars in the MACHO*05:33:49.1–70:13:22 field. The star itself is plotted as the large filled circle.

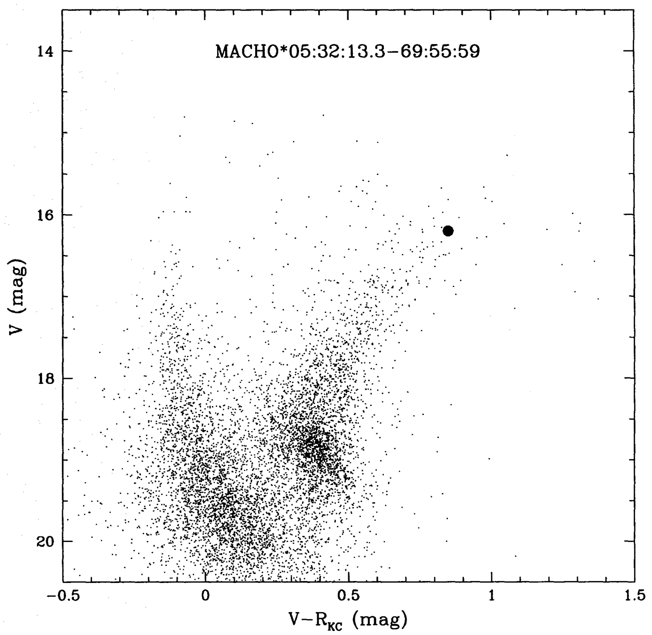

FIG. 6.—Color-magnitude diagram for stars in the MACHO*05:32:13.3–69:55:59 field. The star itself is plotted as the large filled circle.

The spectrum of MACHO∗05:33:49.1–70:13:22, shown in Figure 7, is very similar to that of the hot RCB star, V348 Sgr (Dahari & Osterbrock 1984; Leuenhagen & Hamann 1994). The spectrum of V348 Sgr is classed as WC11, since it shows emission at C II but not C III (Leuenhagen & Hamann 1994). In addition, its light curve, IR excess, and hydrogen deficiency distinguish it as an RCB star. The MACHO∗05:33:49.1–70:13:22 spectrum shows strong C II emission at 3919, 4267, and 4735–4747 Å. There is also possible C II emission seen at 4618–4630 Å, as well as near 4861 Å blended with Hβ. In addition, MACHO∗05:33:49.1–70:13:22 seems to have been detected in the *IRAS* Serendipitous Survey (Kleinmann et al. 1986) at a level of 0.1 Jy at 12 μm. This is similar to the flux detected for HV 12842, and both are consistent with an extrapolation of flux levels measured for Galactic RCB stars. The spectrum, light curve, and IR excess of MACHO∗05:33:49.1–70:13:22 indicate that it is a hot RCB star; it is only the fourth known and the first discovered outside the Galaxy. In addition, although the spectrum is low resolution, the C II lines show a redshift of 259 ± 31 km s^{-1}, which is appropriate for LMC membership.

The spectrum of MACHO∗05:32:13.3–69:55:59 is shown in Figure 8. This spectrum is a stereotypical cool RCB spectrum similar to S Aps and V517 Oph (Kilkenny et al. 1992). The spectrum shows deep Swan bands of C$_2$, with band heads at 4382, 4737, and 5165 Å, and violet bands of CN, with band heads at 3883, 4216, and 4606 Å. In addi-

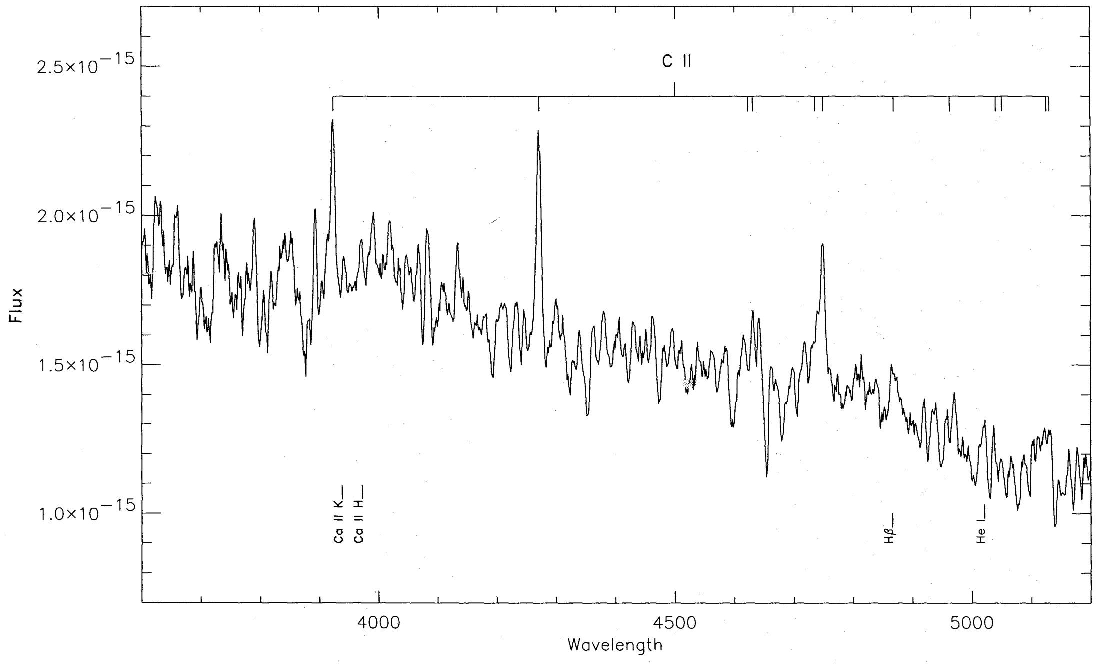

FIG. 7.—Maximum light spectrum of MACHO∗05:33:49.1–70:13:22.

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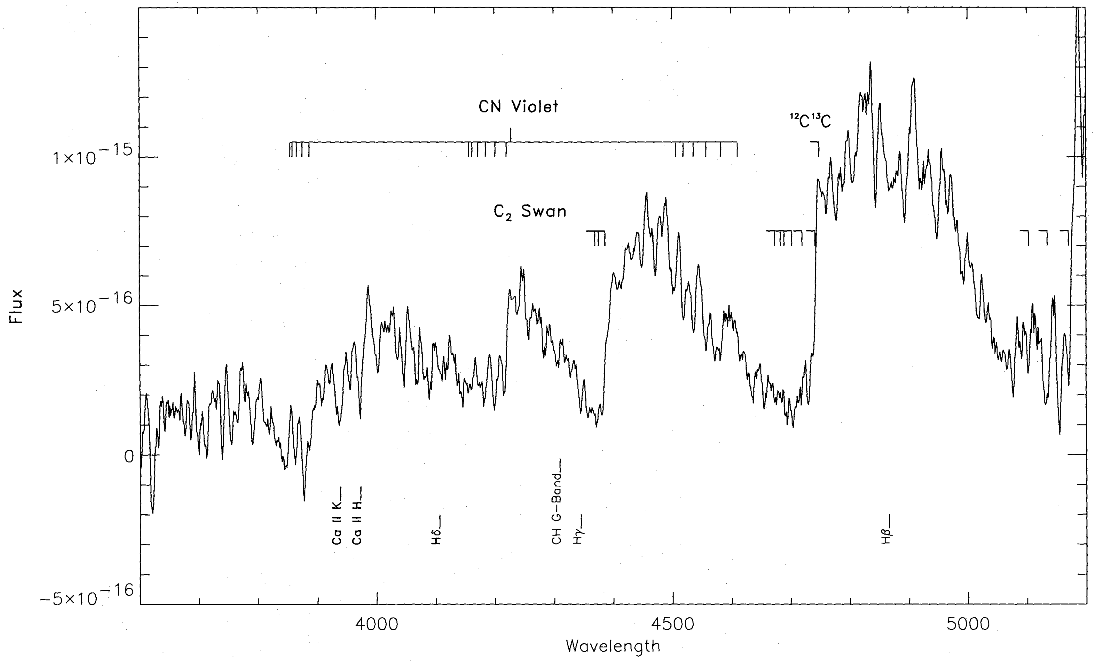

FIG. 8.—Maximum light spectrum of MACHO*05:32:13.3–69:55:59.

tion, the spectrum is distinguished as an RCB star by the weak or absent Balmer lines, G band, and $^{12}C^{13}C$ bands (Lloyd Evans, Kilkenny, & van Wyk 1991). This is a result of severe hydrogen deficiency and a lack of ^{13}C, typically seen in RCB stars (Clayton 1996). MACHO*05:32:13.3–69:55:59 shows a C_2 (1, 0) 4737 Å band that dips about 80% below the continuum. HV 5637 shows a 72% depression and S Aps about 79% (Feast 1972). W Men and HV 12842 show much smaller dips of about 10%, much like R CrB and RY Sgr. The $(V-R)_{KC}$ colors of S Aps and MACHO*05:32:13.3–69:55:59 are similar. The spectrum, color, and light curve of MACHO*05:32:13.3–69:55:59 show that it is a cool RCB star. The measured positions of the molecular band heads show a redshift of 269 ± 21 km s^{-1}, which is appropriate for LMC membership.

As mentioned in the introduction, the distance scale for the RCB stars depends entirely on the LMC members. Using the recent photometry of Lawson et al. (1990), we find V_{max} = 14.8, 13.8, and 13.7 for HV 5637, W Men, and HV 12842, respectively. On the basis of this small sample, RCB stars are supergiants with a range of ~1 mag in absolute luminosity in the V band. Since HV 5637 is cooler than W Men and HV 12842, Feast (1979) suggested a relationship between temperature and luminosity. The observed range in V_{max} is likely to be intrinsic rather than owing to reddening differences. Estimates of foreground (circumstellar and interstellar) reddening are somewhat uncertain, since RCB star colors are not known a priori. Older studies of the Galactic foreground find a fairly uniform screen of dust of $E(B-V) \sim 0.04$–0.07 (e.g., McNamara & Feltz 1980). Schwering & Israel (1991) reexamined the foreground reddening by comparing H I and IR observations. They find a small but significant variation in foreground reddening across the face of the LMC from $E(B-V) = 0.07$ to 0.17 mag. Any constant component of circumstellar dust around RCB stars is small. Using the observed $B-V$ and the estimated T_{eff} listed in Table 2, we calculate $E(B-V) \sim 0.1$–0.2 for HV 5637, W Men, and HV 12842 (Johnson 1966). Goldsmith et al. (1990) estimate 0.08 and 0.10 for the circumstellar and interstellar components of the $E(B-V)$ toward W Men. Only W Men has a measured $(V-R)_{KC}$ (Eggen 1970). Converting this to Johnson, $(V-R)_J$, a similar $E(B-V)$ is obtained, assuming a normal extinction curve with $R_v = 3.1$ (Cousins 1980).

Therefore, the new stars presented here are very important. The measured V_{max} values for these stars are 16.1 and 16.3, fainter by about 2 mag than those for the three known RCB stars. Do these values really represent unreddened V_{max}? These stars have been followed photometrically for only about 3 yr, so it is possible that they have never fully recovered to maximum light. RCB stars go through very active phases in which they are in decline for years (e.g., Mattei, Waagen, & Foster 1991). However, to remain in decline, dust must form regularly to compensate for the dispersal of previous dust clouds. Flat-decline light-curve behavior only occurs deep in a decline, when all direct starlight is extinguished and only scattered light is seen. This kind of behavior is not seen when $\Delta V \sim 2$ mag, so it cannot account for the observed light curve. Therefore, the recent light-curve behavior of both stars, seen in Figures 3 and 4, is consistent with their being at or near maximum light. MACHO*05:33:49.1–70:13:22 seems to be approaching maximum light after a long decline. This light-curve shape is seen in many other RCB declines. The MACHO*05:32:13.3–69:55:59 light curve is more complicated, and the star is definitely in an active phase. However, in the last 200 days, during which time the spectrum was obtained, the star has been very constant, with $\Delta V \sim 0.25$ mag. There is no evidence in this time period for either dust formation or dispersal.

Another possibility is large interstellar extinction toward these stars. The reddening can be estimated from the measured $(V-R)_{KC}$ colors that were converted to $(V-R)_J$ (Cousins 1980). Assuming normal supergiant $(V-R)_J$ colors, $E(B-V)$ is ~0.3 for MACHO*05:33:49.1–70:13:22 and ~0.4 for MACHO*05:32:13.3–69:55:59. This is slightly higher than the estimate of ~0.1–0.2 for the other LMC RCB stars. These values of $E(B-V)$ are seen for many other LMC stars, although most lie in or near the 30 Dor region. Neither of the new LMC RCB stars visibly dusty region of the LMC. Estimates of V_0 and M_V for all five stars are given in Table 2, using the estimated values of $E(B-V)$. The new stars fall $\gtrsim 0.5$ mag below the range of $M_V = -4.1$ to -5.5 for the previously known LMC RCB stars. These estimates are somewhat uncertain because RCB colors may not be the same as normal supergiants. For instance, S Aps has the same maximum-light $(V-R)_{\rm KC}$ color as MACHO*05:32:13.3–69:55:59 and a similar $T_{\rm eff}$ (Lawson et al. 1990), yet its $B-V$ colors imply a smaller reddening of $E(B-V)$ of ~ 0.1. If the reddening of MACHO*05:32:13.3–69:55:59 is 0.1, then it has an even fainter $M_V \sim -2.6$. Another indication of the uncertain reddening correction can be seen in Figures 5 and 6. The stars in the MACHO*05:33:49.1–70:13:22 field seem to be ~ 0.1 mag redder than the stars in the MACHO*05:32:13.3–69:55:59 field. Therefore, taking into account the uncertainties in the intrinsic and measured colors, and stellar $T_{\rm eff}$, the uncertainty in $E(B-V)$ is ~ 0.1–0.2. Thus, the uncertainty in M_V is ~ 0.3–0.6.

A slightly smaller range of values is found when using $M_{\rm bol}$. The assumed effective temperatures are 5000 and 7000 K for cool and warm RCB stars, respectively. Using the values of M_V calculated above and bolometric corrections for normal supergiants, we get the values listed in Table 2 for $M_{\rm bol}$. A value of 20,000 K has been estimated for V348 Sgr (Schönberner 1986). This value has been applied to MACHO*05:33:49.1–70:13:22. Its $M_{\rm bol}$ lies in the range of the warm RCB stars. The two cool RCB stars have the lowest bolometric luminosities. The question of whether LMC and Galactic RCB stars are intrinsically different remains open. There are abundance differences, but they may lie within the range of variations seen in the Galactic RCB stars. The slightly bluer *UBV* colors of the LMC RCB stars may also be an indication of abundance differences.

5. SUMMARY

1. The discovery of new LMC RCB stars brings to five the number known. Most importantly, one is a rare hot RCB star.
2. The wider range of $T_{\rm eff}$ now existing does not support the suggestion of a relationship between $T_{\rm eff}$ and M_V. However, the two cool RCB stars have the lowest bolometric luminosities.
3. The new stars presented here suggest that there is a wider range of absolute visible magnitude than given by the canonical $M_V \sim -4$ to -5. Therefore, the absolute luminosities of RCB stars are now less certain, since they are based solely on the LMC stars.
4. This pilot project shows the value of the MACHO photometric database for the discovery of new RCB stars in the LMC. Based on the success of this project, more RCB stars will be found in the future. Increasing the sample of stars is the only way to resolve the uncertainty about the absolute luminosities of the RCB stars.

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